Chapter 5

Identify and Select Solutions

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Chapter 5

Identify and Select Solutions

This chapter integrates the information provided in previous chapters to identify and select preferred treatment alternatives. The key points made in the previous chapters are reinforced in this chapter, including identifying the mechanisms and causes of failure, defining design criteria, considering mitigation, and evaluating "no action" alternatives. Additionally, this chapter will help the reader:

- become familiar with the concept of integrating the results from the site and reach assessments into the selection of streambank-protection treatments,
- make use of a series of matrices for identifying and selecting appropriate bank-protection techniques,
- review three case studies that demonstrate how to use the screening matrices,
- explore further techniques that may be appropriate for resolving common site- and reach-based erosion problems, and
- incorporate design considerations to guide the selection of a treatment solution.

PRESELECTION CONSIDERATIONS

Identifying the Mechanisms and Causes of Failure

Identifying suitable bank-protection alternatives begins with understanding the specific mechanisms of failure at a project site (Chapter 2, *Site Assessment*), as well as the reach-based causes of bank instability (Chapter 3, *Reach Assessment*). These site- and reach-based causes of bank erosion may be simple and discreet, or they may be highly interdependent and difficult to separate. Nonetheless, it is only through the process of identifying mechanisms and causes of failure that appropriate solutions can be developed.

It's important to consider a number of reach-wide factors when designing streambank-protection measures, including whether a project reach is in short-term or long-term disequilibrium. Where instability is caused by problems that extend throughout the watershed, then the selection of bank-stabilization measures needs to account for these conditions. For example, where a reach is degrading, bank protection must either account for the effects of scour (if the channel bed continues to drop), or it must prevent further degradation by some means (such as an at-grade bed control).

Objectives and Design Criteria

In order to identify and select appropriate bank-protection techniques, it is necessary to develop a series of design criteria that quantify the general project objectives (Chapter 4, *Considerations for a Solution*). These criteria, which take into consideration risk and cost and line up according to relative priority, are intended to outline the objectives of the project and provide the foundation for making design decisions about the specific sizes and components of bank-protection techniques.

Mitigation

Every bank-protection project should be evaluated with respect to potential mitigation requirements. Avoiding impacts completely should be the first consideration before designing a project. If impacts are unavoidable, they should be minimized, and compensatory mitigation will be necessary. The preferred approach is as follows:

- First - avoid impact,
- Second - minimize and compensate for impacts, and
- Third - compensate for the impacts.

Chapter 4 addresses mitigation requirements in more detail.

No Action

When identifying an appropriate bank-protection technique, keep in mind that the best course of action for a stream might be to take no action at all (Chapter 4). After considering the forces causing streambank erosion, it may become apparent that this natural process is too difficult or costly to arrest or change, or that the system-wide disequilibrium is too extensive to control locally. It might be more cost-effective to reduce or eliminate the need for bank protection at all. For example, if a migrating river channel threatens a structure, it might require less expense, effort and impact to move the structure a safe distance from the river than to apply bank protection.

It might be more cost-effective to reduce or eliminate the need for bank protection at all.

SELECTION PROCESS

A series of matrices are provided in this chapter to assist in identifying and selecting bank-protection and habitat-mitigation techniques. What matters most in selecting treatments is the specific site- and reach-based aspects of each individual project, so special care should be taken in evaluating these aspects before selecting treatments. Be sure to review Chapters 1 through 4 to learn how to assess site and reach conditions and other design considerations before selecting a bank-protection technique for a specific site. Doing so will help determine the most appropriate and successful course of action. You'll find more detailed information about the bank-protection techniques identified in this section in Chapter 6, *Techniques*. It is not at all unusual to find that combining two or more streambank-protection techniques produces more successful results, depending upon the goal to be achieved, different functions at play or different effects on habitat. Given the opportunities to combine these treatments, it is important to encourage creativity in designing bank protection, as long as design criteria are met.

Be sure to take the time to review the three case studies that follow the discussion on the screening matrices. They will help demonstrate the selection process using the matrices.

BANK-PROTECTION TECHNIQUES

The various bank-protection techniques described in these guidelines have been divided into functional groups, making it easier to determine the applicability of particular bank-protection techniques for differing site and reach conditions. *Table 5-1* lists each of the techniques, which are described in detail and by category in Chapter 6, *Techniques*. These groups include:

- no action,
- instream flow-redirection techniques,
- structural bank-protection techniques,
- biotechnical bank-protection techniques,
- internal bank-drainage techniques,
- avulsion-prevention techniques, and
- other techniques.

Flow-Redirection Techniques influence the flow patterns and hydraulics of a stream in order to reduce the erosive forces acting on a bank or bed. The changes in hydraulics involve shifts in flow distribution across the channel, average velocity in the cross section, or distribution of energy. Instream flow-redirection techniques involve placing materials within a channel, rather than strictly along a bank. These techniques directly and/or indirectly affect channel cross-sectional shape, erosion and deposition patterns, channel roughness, and hydraulic slope and capacity. The risks of these changes to adjacent property must be fully understood and appropriately managed before attempting such projects. If proper care is not taken to fully understand potential impacts, unintended damage to property can be severe.

Structural Techniques directly affect the structure of the bank to shield it from scour, strengthen it or structurally support it. For bank protection, structural techniques include rock and log toes and revetments. For bank strengthening and support, log cribwalls can be used. Structural support and strengthening are often combined with biotechnical bank-protection techniques to provide a stable foundation that allows installed vegetation to survive.

Biotechnical Techniques use vegetation and wood to reproduce the natural system and to provide structural and surface erosion protection. For the purposes of this document, biotechnical techniques are defined as consisting of entirely biodegradable components (for example, natural-material erosion-control fabrics, willow cuttings and large woody debris). One major benefit of biotechnical techniques over structural techniques is that vegetative methods are self-healing. That is, vegetation continues to grow, and large, woody material continues to be contributed as it falls into the stream. In an ecologically diverse and productive river system, its banks and channel will contain many pieces of large woody debris, and vegetation will be densely distributed along the banks.

No Action	Flow-Redirection Techniques	Structural Techniques	Biotechnical Techniques	Internal Bank-Drainage Techniques	Avulsion-Prevention Techniques	Other Techniques
Allow bank erosion to continue Move structures at risk	Groins Buried groins Barbs Engineered log jams Drop structures Porous weirs	Anchor points Roughness trees Riprap Log toes Rock toes Log cribwalls Manufactured retention systems	Woody plantings Herbaceous cover Soil reinforcement Coir logs Bank reshaping	Subsurface drainage systems	Floodplain roughness Floodplain grade control Floodplain flow spreader	Channel modifications Riparian-buffer management Spawning-habitat restoration Off-channel spawning and rearing habitat

Table 5-1. Bank-protection techniques organized by functional group.

Biotechnical techniques mimic this condition. Vegetation and wood provide shade for temperature control as well as serve a food source and cover for fish and wildlife. They also cause pools to scour, resulting in improved fish habitat. A combination of biotechnical, flow redirection and structural techniques are typically used in bank-protection projects.

Internal Bank-Drainage Techniques are methods that provide for water to drain from within a streambank, whether caused by rapid drawdown or seepage from groundwater. These techniques are typically integrated with structural and biotechnical techniques and are seldom used independently.

Avulsion-Prevention Techniques reduce the potential for an avulsion, rather than providing a remedy once one has occurred. Avulsion-prevention techniques distribute and dissipate flood flows and prevent headcut development across a vulnerable floodplain area.

Channel Modification Techniques are used to change the channel geometry and/or planform to provide for more natural and stable conditions. Channel modifications can be designed to account for changing watershed conditions, such as sediment and flows, and to improve aquatic habitat in reaches of the channel that have been impacted. Channel modifications require an understanding of site- and reach-based conditions, and a thorough design approach. An abbreviated discussion of channel modifications can be found in Chapter 6.

Riparian-Buffer Management Techniques provide cover and shade, a source of fine or coarse woody material, nutrients, and organic and inorganic debris - all of which are essential for river and stream ecosystems function. Riparian buffers also provide habitat for wildlife, especially migrating and breeding birds. Examples of riparian-buffer management techniques include: conservation easements, fencing livestock out of the riparian zone and plantings.

SELECTING BANK-PROTECTION METHODS USING SCREENING MATRICES

One of the most difficult but important aspects of the design process involves moving from identifying the mechanism and causes of failure to the selection of an appropriate solution. To provide a tool for people with varying levels of experience, three screening matrices are presented. The matrices are configured to assist in selecting treatments that:

- perform adequately to meet bank-protection objectives;
- are appropriate with respect to site-based and reach-based processes;
- are properly weighed against their potential impacts to habitat; and
- are selected in an order of priority that first avoids, second minimizes, and third compensates for habitat impacts.

The three matrices act as progressively selective screens, or filters, of bank-protection techniques. Within each matrix, the techniques have been arranged according to their functional groups (no action, instream flow-redirection, structural, biotechnical, internal bank drainage, avulsion- and chute-cutoff prevention, and other). With each subsequent matrix, inappropriate techniques are progressively "screened out" by process of elimination, leaving an assortment of feasible treatment options.

One of the most difficult but important aspects of the design process involves moving from identifying the mechanism and causes of failure to the selection of an appropriate solution.

Screening Treatments Based on Site Conditions

Matrix 1 (*see Figures 5-1a and 5-1b on pages 5-9 and 5-10*) identifies several bank-protection techniques that should be considered in resolving the mechanisms of failure occurring at your site. It also identifies whether the no-action option should be considered. Start by identifying the mechanisms of failure that apply to your site. (In Matrix 1, see the columns "Is This Occurring at My Site?" and "Mechanism of Failure.")

In the first column, check ("√") each mechanism of failure that is occurring at your site. If you are not sure about a particular mechanism of failure, read Chapter 2.

Matrix 1 identifies several bank-protection techniques that should be considered in resolving the mechanisms of failure occurring at your site. It also identifies whether the no-action option should be considered.

Next, look across the row for each identified mechanism of failure, and circle all the techniques that are rated as "Good" at resolving this failure. (If there are no techniques rated as "Good," then select those rated as "Fair.") These are techniques that may be good options for your site. Do this for each type of failure you have identified. At the bottom of the matrix, sort through the techniques you've circled, identifying those that appear to best meet your site-based needs. Where there is more than one mechanism of failure, select the dominant mechanism and identify techniques repeatedly circled as "Good" (or those marked "Fair" if no "Good" options apply) that apply to it. Place greater weight on these techniques in the selection process.

To indicate which techniques are suitable and which are not, mark each technique that best meets your site-based needs in the bottom row with a "S" for suitable; mark those that are unsuitable with a "U." These unsuitable techniques may need to be revisited if the remainder of the screening process does not result in an acceptable choice.

Screening Treatments Based on Reach Conditions

Matrix 2 (*see Figures 5-2a and 5-2b on pages 5-11 and 5-12*) is used to identify bank-protection techniques that apply to the reach-wide conditions of the stream at your site (see Chapter 3). Begin by transferring the bottom row of Ss in Matrix 1 (in the row called "Suitability of Each Technique") to the first row in Matrix 2 (in the row also called "Suitability of Each Technique"). Take care to ensure that the Ss correspond to the same technique in each matrix. Check ("√") the first column adjacent to the reach-based conditions that describe your site. If you are not sure which may apply, read Chapter 3. Now, based on the screening thus far, only those rows where you placed a "√" and those columns where you placed an S should relate to your site. Read across the checked rows, circling all the techniques rated "Good" that you marked with an S (circle those rated as "Fair" if there are not any "Good" options available). Here, consider only those techniques that apply to both conditions at your site.

Matrix 2 is used to identify bank-protection techniques that apply to the reach-wide conditions of the stream at your site.

At the bottom of Matrix 2, sort through the techniques, identifying those that appear to best meet your needs. Where there are multiple reach-based conditions at work, focus on the dominant condition and identify those techniques that are repeatedly circled as "Good" (or those marked "Fair" if no "Good" options apply). Place greater weight on these techniques in the selection process. For those techniques that rank as suitable, mark them in the bottom row with an S. Those that are not suitable should be marked with a U. Here again, those techniques marked as unsuitable for now might need to be revisited if the screening process does not result in an acceptable choice.

Selecting Treatments Based on Habitat Impacts

The suitable techniques carried over from Matrices 1 and 2 are acceptable for your project based on specific site and reach conditions. Matrix 3 (*see Figures 5-3a and 5-3b on pages 5-13 and 5-14*) identifies the potential habitat impacts that these techniques might cause. It also identifies compensatory mitigation techniques for these impacts. The objective is to combine, or integrate, two or more techniques in order to achieve site-stability objectives, while avoiding or minimizing impacts to habitat. For a discussion of habitat and mitigation policies, objectives and targets, read Chapter 4. For the protection of fish habitat, mitigation sequencing must be used in the selection of the bank-protection technique. The sequence of mitigation activities is first to avoid the impact and, second, to minimize and compensate for any impacts that are unavoidable.

Matrix 3 identifies options that will avoid and/or minimize impacts and those that will compensate for losses. The matrix lists bank-protection and compensatory mitigation techniques in the top row. Habitat functions are listed in the left column: riparian function, cover, spawning, complexity and diversity, lost opportunity, construction and flood refuge. These functions are described in Chapter 4.

Matrix 3 identifies the potential habitat impacts that these techniques might cause. It also identifies compensatory mitigation techniques for these impacts.

Matrix 3 is constructed to reflect the mitigation sequence. The letter "A" (avoid) is shown in each cell for the techniques that generally avoid impacts to the habitat function of that row. Choices that impact habitats are marked as: "L" for low-impact, "M" for medium-impact and "H" for high-impact. Realize that there will be many situations that are exceptions from the matrix, due to specific habitat requirements or unique site conditions. If this is the case for the site under consideration, then describe the unique or special conditions and how they are accommodated.

To begin using Matrix 3, transfer the treatments marked with an S on bottom row of Matrix 2 to the first row of Matrix 3. If there are no suitable techniques that avoid impacts, look for techniques that minimize impacts, first considering techniques that have low, then medium and then high impacts, in that order. For every low-, medium- or high-impacting technique, you must provide a technique that compensates for the impact. Techniques that compensate for a particular habitat function are identified with a "C" in the rows under "Mitigated By."

Many specific techniques have a mix of C's, L's, M's, H's and A's in the rows associated with "Impacts To." Where this is the case, consideration and weight must be given to those functions that achieve the mitigation target. Mitigation targets are described in Chapter 4. The target may favor improvement of factors within the watershed that limit fish production, restore properly functioning habitat, and replicate natural the techniques.

Refer to Chapter 6 for further details on application, design and effects of each of the techniques.

MATRIX 1: SCREENING TREATMENTS BASED ON SITE CONDITIONS
Refer to Chapter 2 for Site-Based Assessment Information

		Potential Suitability of Bank-Protection Techniques																									
		No Action	Other Techniques		Flow-Redirection Techniques							Structural Techniques							Biotechical Techniques					Internal Bank-Drainage Techniques	Avulsion-Prevention Techniques		
Is This Occurring at My Site? (**Y**es or **N**o)	**Mechanism of Failure**		Channel Modifications	Riparian-Buffer Management	Groins	Buried Groins	Barbs	Engineered Log Jams	Drop Structures	Porous Weirs	Remove or Reduce Feature	Anchor Points	Roughness Trees	Riprap	Log Toes	Roughened Rock Toes	Log Cribwalls	Manufactured Retention Systems	Woody Plantings	Herbaceous Cover	Soil Reinforcement	Coir Logs	Bank Reshaping	Subsurface Drainage Systems	Floodplain Roughness	Floodplain Grade Control	Floodplain Flow Spreader
	TOE EROSION																										
	Reduced Vegetative Structure	F	I	G	G	G	G	G	F	F	-	D*	G	F	G2	G2	F	F	G	G2	G	G	G2	-	-	-	-
	In a Smoothed Channel	F	G	G2	G	G	F*	G	G2	G2	-	I	G	F	G2	G2	F	F	G2	F2	F	G2	G2	-	-	-	-
	Along a Bend	G	D	G2	G	G	G	G	F	F	-	D*	G	G	G	G	G*	G	G2	G2	G	G2	G2	-	-	-	-
	SCOUR																										
	Local Scour																										
	At a Tailout or Backwater Bar	G	I	G2	F*	F	F	D	F	F	G	G	G	G	G	G	G	D*	G2	G2	G2	G2	F2*	I	I	I	I
	Associated with an Obstruction	G	I	G2	F*	F	F	D	F	F	G	G	G	G	G	G	G	D*	G2	G2	G2	G2	F2*	I	I	I	I
	Constriction Scour																										
	Associated with Large Woody Debris Jam	G	F	G2	F*	F	F*	G*	P*	P*	G	G*	F*	F	G*	F*	F	D*	G2	G2	G2	G2	F2	I	I	I	I
	At a Bridge Crossing	F	I	I	D*	I	D*	D*	D*	P*	G	I	I	G	P	G	I	G*	I	I	I	I	G2	I	I	I	I
	At Existing Bank Feature	G*	G	G2	D*	G	D*	D*	P*	P*	D*	G*	F*	F	G	F	F	D*	G2	G2	G2	G2	F2	I	I	I	I
	Drop/Weir Scour	G	D	G2	D	I	I	D	F*	P*	D	F	G*	F	G	F	F	D*	G2	G2	G2	G2	F2	I	I	I	I
	Jet Scour																										
	At a Lateral Bar	G	D	G2	D	F	D	D	F	F	F2	G	G	P*	G*	F*	G	D*	G2	G2	G2	G2	F2	I	I	I	I
	At a Side Channel or Tributary	G	D	G2	G*	G	I	D	I	I	D*	G	G	F	G2	G2	G	D*	G2	G2	G2	G2	F2	I	I	I	I
	Subchannels in a Braided Channel	G	D	G2	P	P	P	P	I	I	I	P*	F	F*	F2*	F2*	F*	D*	G2	G2	G2	G2	F2	I	I	I	I
	At a Channel Bend (Energy Sink)	G	D	G2	D	I	I	D	F2*	F2*	I	G	G	F	G2	G2	G	F*	F2	F2	G	F2	F2	I	I	I	I
	SUBSURFACE ENTRAINMENT																										
	Groundwater Seepage	G	D	I	F	F	F	F	P	P	F	I	F	G2	G	G	G2	G2	G2	G2	G2	G2	G2	G	I	I	I
	Rapid Drawdown	G	D	I	F	F	F	F	P	P	F	I	F	G2	G	G	G2	G2	F2	F2	F2	F2	F2	G	I	I	I
	MASS FAILURE																										
	Saturated Soils	G	D	I	F*	I	F*	F*	P	P	-	I	F2	F*	G2*	G2*	F	G*	D*	I	P	I	G2	G	I	I	I
	Increased Surcharge	F	S	I	P*	I	P*	P*	P*	P*	G	I	P*	F*	P*	P*	F	G*	P*	P*	F	I	G2*	I	I	I	I
	Lack of Root Structure	F	D	G2	I	I	I	I	I	I	I	I	I	F*	G2	G2	F	F	G2	P	F	F2	G2	I	I	I	I
	Undercutting/Removal of Lateral/Underlying Support	D	D	I	I	I	I	I	I	I	I	I	I	F*	G	G	F	F	F2	P	F	F2	G2	I	I	I	I
	AVULSION POTENTIAL																										
	In Mature Floodplain	G	D	G	I	I	I	I	I	I	-	I	I	I	I	I	I	I	I	I	I	I	I	-	F	P	F
	In Channel Floodplain	I	D	G	I	I	I	I	I	I	-	I	I	I	I	I	I	I	I	I	I	I	I	-	G	G	G
	CHUTE-CUTOFF POTENTIAL																										
	In Mature Floodplain	G	D	G	G	G	G	G	F	F	-	I	G	G	G	G	G	G	G2	G2	G	G2	F	-	F	I	I*
	In Channel Floodplain	I	D	G2	G	G	G	G	F	F	-	I	G	G	G	G	G	G	G2	G2	G	G2	F	-	G	G	G
	Suitability of Each Technique **S**uitable/**U**nsuitable																										

Level of Suitability
* = See Figure 5-1 (b) for additional explanation
G = Good. Directly addresses human-caused mechanism of failure, site-based, or reach-based cause, or allows mechanism of failure to correct itself, or allows mechanism of failure to continue when appropriate, or directly the addresses (corrects) hydraulic condition created by the reach-based cause.
G2 = Good in combination with a technique rated G or in low to moderate risk situation.
F = Fair. Does not address mechanism of failure, site-based, or reach-based cause. Is not as good a bank protection solution as "good."
F2 = Fair in Combination with a Technique Rated for G.
P = Poor. Does not address mechanism of failure, site-based, or reach based cause. Not as good a bank protection solution as "fair."
I = Inappropriate. Does not work., and does not address mechanism of failure, site-based, or reach-based cause.
D = Dependent upon Site Conditions. Too varied to generalize in this matrix.
- = Not Applicable.

Notes:

1. The matrix ratings are general.; there will be situations that are exceptions to the matrix ratings. Each should stimulate further discussion. The ratings don't compare feasability, cost or risk.

2. The tables following each of the matrices include explanations of some of the ratings in the matrices. Explanations are given for those ratings that are not obvious or are incomplete without some explanation.

3. See Chapter 5 for instructions on how to use this matrix.

Figure 5-1(a). Matrix 1: Screening techniques based on site conditions.

MATRIX 1: SCREENING TREATMENTS BASED ON SITE CONDITIONS
Explanation of Matrix 1 Ratings

MECHANISM OF FAILURE		TECHNIQUE	RATING	EXPLANATION OF RATING
All		No action	G, F, I, D	"No action" is always an option. It does not rate "good" if mechanism of failure is human-caused. "No action" may involve the decision to simply take not action. "No action" may also involve solving the problem by undertaking "out-of-channel activities" (such as moving a building or structure) rather than implementing bank protection.
General bank erosion	Smoothed channel	Barbs	F	Not enough roughness.
	Smoothed channel	Log cribwalls	F	Assumes cribwall is roughened.
	Reduced vegetation, Along a bend	Anchor points	D	Depends on scale of channel and erosion. Anchor points are intended for local scour.
Scour		Manufactured retention systems	G, F, P, D	Might apply if the bank is also slide-prone; refer to mass failure.
Local scour	Scour at tailout, backwater, or obstruction	Groins	F	Structures placed upstream of scour to improve flow alignment.
Local scour	Scour at tailout, backwater, or obstruction	Bank reshaping	F2	Does not solve scour; bank reshaping is done to support planting.
Constriction scour		Various techniques	G,F	Often inappropriate since constriction scour is defined here as in the bed only. Some techniques apply where they would support a bank that could otherwise be undermined by the scour. That condition does not occur where a channel is confined (bridges).
	Associated with debris	Drop structures, porous weir	P	Used to backwater the constriction. Poor because debris jam is transient, structures are not.
		Flow-redirection techniques	G	Engineered log jam is transient and flexiblle, other flow redirection techniques are not.
		Groins, barbs	F	Debris is transient, rock is hard and permanent.
		Log toe	G	Allows bed scour if log toe is supported by bank.
		Rock toe	F	Fails with continued bed scour unless adequate roughness is added. Roughness will exacerbate constriction.
	Associated with debris, at existing bank feature	Anchor point	G	Assumes feature is natural and can be reinforced to form anchor point.
		Roughness trees	F	Allows bed scour to continue; trees can span scour hole and support bank, but assumes roughness exaerbates constriction.
	Bridge	No action	F	Assumes the mechanisms of failure are human caused. Other causes are G. See the definition of "G" rating.
		Manufactured retention system	G	For example, sheet pile at toe of footing.
		Bank reshaping	G2	Remove sloping fill under bridge in conjunction with other retention system.
		Flow-redirection techniques	G, F, P, D	Place upstream to align the channel more efficiently to the constriction.
	At existing bank feature	No action	G	Assumes feature is natural.
		Remove or reduce feature	D	An existing groin or other artificial constriction might be modified.
Drop/weir scour		Groins	D	Groins are downstream to roughen channel and create backwater.
		Drop structures	F	Cannot redirect flow effectively to a drop. May be used to backwater drop.
		Porous weir	P	Cannot redirect flow effectively to a drop. Less effective backwater than drop structure.
		Roughness trees	G	Allows bed scour to continue. Trees can span scour hole and support bank.
Jet scour	At lateral bar	Riprap	P	Lateral bar may be transient.
		Log toe	G	Assumes scour occurs at a moderate flow when toe protection is more effective.
		Rock toe	F	Assumes scour occurs at a moderate flow when toe protection is more effective. Rock toe is permanent; lateral bar may be transient.
	At tributary	Groins	G	Groins intended to scour tributary bar.
		Remove or reduce feature	D	Gravel removal might be appropriate if it is a one-time event.
	Braided subchannel	Anchor points	P	Channels are transient and may impact between anchor points.
		Structural techniques	F	Subchannel is transient in location and time.
	At abrupt channel bend (energy sink)	Drop structures, porous weir	F2	Located upstream to dissipate and direct flow, or located downstream to backwater. Use with anchor point.
		Riprap	F	Tends to fills energy sink and lose energy-dissipation volume; fails if scour hole deepens.
	Groundwater seepage	Riprap	G2	Needs drainage to make riprap secure.
	Rapid drawdown	Biotechnical techniques	F2	Drawdown implies a "no-grow zone" where vegetation is less effective.
	Groundwater seepage, Rapid drawdown	Groins, barbs, engineered log jam	D	Does not address problem. but could fix channel in place away from problem or let bank recline.
Mass failure	All	Riprap	F	Assumes riprap is a buttress.
	Saturated soils	Log toe, Rock toe	G2	Assumes bank can be reshaped and planted to a stable slope.
		Groins, barbs, engineered log jam	F	Does not address cause, but could fix channel in place away from problem or let bank recline. Seepage continues until bank is in equilibrium.
		Manufactured retention system	G	Assumes it contains appropriate drainage.
		Woody Plantiings	D	Depends on depth of failure.
	Increased surcharge	Various flow-redirection, structural, and biotechnical techniques	P	Assumes there is a structure on the bank (surcharge) that will fail unless the entire bank is stabilized.
		Reshape bank	G2	Assumes that the surcharge is moved.
	Increase surcharge, lack of root structure	No action	F	Assumes the mechanisms of failure are human caused. See the definition of "G" rating.
Chute cutoff	Mature floodplain	Flow spreader	I	Assumes disturbance of mature forest in floodplain.

Figure 5-1(b). Matrix 1: Explanations of ratings in Matrix 1.

MATRIX 2: SCREENING TREATMENTS BASED ON REACH CONDITIONS
Refer to Chapter 3 for Reached-Based Assessment Information

Potential Suitability of Bank-Protection Technique

Is This Occurring at My Site? (Yes or No)	How Does This Technique Perform → Under This Condition ↓	No Action	Other Techniques		Flow-Redirection Techniques							Structural Bank-Protection Techniques							Biotechical Techniques					Internal Bank-Drainage Techniques	Avulsion-Prevention Techniques		
			Channel Modifications	Riparian-Buffer Management	Groins	Buried Groins	Barbs	Engineered Log Jams	Drop Structures	Porous Weirs	Remove or Reduce Feature	Anchor Points	Roughness Trees	Riprap	Log Toes	Roughened Rock Toes	Log Cribwalls	Manufactured Retention Systems	Woody Plantings	Herbaceous Cover	Soil Reinforcement	Coir Logs	Bank Reshaping	Subsurface Drainage Systems	Floodplain Roughness	Floodplain Grade Control	Floodplain Flow Spreader
	Suitability of Each Technique From Matrix 1:																										
	REACH IN EQUILIBRIUM																										
	Meander Migration																										
	Within Channel-Migration Zone	G	I	G	P	G	P	F	P	P	-	D*	G	P	G	P	F	P	G	G2	G	G	G2	-	-	-	-
	At Edge of Channel-Migration Zone	G	I	G	G	G	G	G	F	F	-	D*	G	G	G2	G2	G	G	G	G2	G	G	G2	-	-	-	-
	REACH IN DISEQUILIBRIUM																										
	Large-Scale Flood Events	D*	D	G	D	D	D	D	D	D	-	D*	D	D	D	D	D	D	G	G2	G	G	G2	-	-	-	-
	Aggrading Reach																										
	Reduced Hydrology/ Increased Sediment Supply	D*	D*	G	G*	F	P	G	I	I	G2*	D*	G	G	F2*	F2*	G	G	G	G2	G	G2*	G2	-	-	-	-
	Downstream Constriction	P	F	G	F*	F	P	F	F*	I	G	D*	F	F	F2*	F2*	F	F	G	G2	G	G2*	G2	-	-	-	-
	Reduced Slope or Downstream from Confined Reach	D*	D*	G	F*	P	I	P	F*	I	-	D*	D	F	F2*	F2*	F	F	G	G2	G	G2*	G2	-	-	-	-
	Confined Channel (with Dikes/Berms)	P	G	G	I	I*	P	I	I	I	G	D*	D	F	F2*	F2*	F	F	G	G2	G	G2*	G2	-	-	-	-
	Degrading Reach																										
	Increased Hydrology/ Reduced Sediment Supply	D*	G	F2*	F*	F	P	G*	G	G	G*	D*	G	P	F	F	P*	P*	F2	P	F*	P	F2	-	-	-	-
	Shortened Channel	P	G	F2*	G	G	P	G	G	G	-	D*	F	F	F	F	I	I	F2	P	F	P	F2	-	-	-	-
	Natural Channel Evolution (Headwater Streams)	G	G	F2*	P	P	P	G	F*	F*	-	D*	P	P	F	F	I	I	F2	P	F*	P	F2	-	-	-	-
	AVULSION POTENTIAL																										
	Aggrading Reach	D	I	G	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	G	F	G
	Localized Downstream Constriction	P	G	G	I	I	I	I	I	I	G	I	I	I	I	I	I	I	I	I	I	I	I	I	G	G	G
	Previously Relocated Channel	P	G	G	I	I	I	I	I	I	G	I	I	I	I	I	I	I	I	I	I	I	I	I	G	G	G
	Braided Channel	D	I	G	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	G	F	F
	Large Storm Event	D	I	G	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	G	G	G
	Suitability of Each Technique From Matrix 2: **S**uitable/**U**nsuitable																										

Level of Suitability
* = See Figure 5-2 (b) for additional explanation.
G = Good. Directly addresses human-caused mechanism of failure, site-based, or reach-based cause, or allows mechanism of failure to correct itself, or allows mechanism of failure to continue when appropriate, or directly the addresses (corrects) hydraulic condition created by the reach-based cause.
G2 = Good in combination with a technique rated G or in low to moderate risk situation.
F = Fair. Does not address mechanism of failure, site-based, or reach-based cause. Is not as good a bank protection solution as "good."
F2 = Fair in Combination with a Technique Rated for G.
P = Poor. Does not address mechanism of failure, site-based, or reach based cause. Not as good a bank protection solution as "fair."
I = Inappropriate. Does not work., and does not address mechanism of failure, site-based, or reach-based cause.
D = Dependent upon Site Conditions. Too varied to generalize in this matrix.
— = Not Applicable.

Notes:

1. The matrix ratings are general; there will be situations that are exceptions to the matrix ratings. Each should stimulate further discussion. The ratings don't compare feasability, cost, or risk.

2. The tables following each of the matrices include explanations of some of the ratings in the matrices. Explanations are given for those ratings that are not obvious or are incomplete without some explanation.

3. See Chapter 5 for instructions on how to use this matrix.

Figure 5-2(a). Matrix 2: Screening techniques based on reach conditions.

MATRIX 2: SCREENING TREATMENTS BASED ON REACH CONDITIONS Explanation of Matrix 2 Ratings				
REACH-BASED CAUSE		**TECHNIQUE**	**RATING**	**EXPLANATION OF RATING**
EQUILIBRIUM, DISEQUILIBRIUM				
All	All	Anchor points	D	Anchor points may be appropriate wherever local scour is occurring regardless of the reach condition, except for avulsions.
	Large flood event	All	D	Action depends upon probability of flood recurrence and whether it left the reach vulnerable to increased erosion.
REACH IN DISEQUILIBRIUM				
All		No action	D	Reach conditions should be addressed if a bank-protection project is built. This is not meant to say that the project should be built for the purpose of correcting reach conditions.
Aggrading reach	All	Woody plantings	G	Woody plantings in floodplain provide roughness and enforce banks.
		Log toe, rock toe	F2	Toe treatments may get buried. Need complementary bank treatments.
		Coir logs	G2	Toe treatments may get buried. Assumes coir logs can cover bank or includes complementary bank treatment.
	Reduced hydrology/increased sediment, Downstream constriction, Reduced slope	Groins, roughness trees	G, F, P	Roughness techniques can be appropriate when overall roughness is small compared to scale of channel so thalweg is moved away from bank but overall backwater is not increased.
	Downstream constriction, Reduced slope	Drop structures	F	Use to concentrate flow into single channel.
	Reduced hydrology / Increased sediment supply	Channel modificatiion	D	Sediment sump or dredging might be reasonable if increased sediment is temporary and not likely to recur. Levees usually increase flood hazard risk in this situation.
		Remove or reduce feature	G2	"Remove or Reduce feature" means removal or reduction (remedy) of source of excess sediment. Protection is not immediate so a complementary measure is needed.
	Reduced slope	Roughness trees	D	Can be good bank protection if roughness is small scale compared to channel so it does not affect conveyance by roughness or constriction.
	Confined channel	Buried groins	I	Assumes groins cannot be set far enough from the channel, therefore the channel cannot expand to its natural width.
Degrading reach	All	Riparian-buffer management	F2	Does not resolve degradation. Riparian zone may become perched on terrace.
	Increased hydrology / Reduced sediment supply	No action	D	"No action" may be appropriate if channel is approaching equilibrium.
		Groins	F	Roughness generally good for degrading channel. Rigid structures may be undermined and fail.
		Engineered log jam	G	Better than groin since log jam is more resilient.
		Cribwalls, manufactured retention systems	P	Assumes structures constrict the channel, without maximizing roughness. Structures may be undermined and fail.
		Soil reinforcement	F	Same as cribwalls but more flexible.
		Remove or reduce feature	G	"Remove or Reduce Feature" means restoration of natural sediment load. Protection is not immediate, so complementary measure is likely needed.
	Natural channel evolution	Drop structures, porous weirs	F	Bed structures create nick points in bed as channel continues to degrade. They will break down into the channel if they are erodible rather than hard, fixed structures.
		Soil reinforcement	F	Assumes soil reinforcement does not constrict the channel. Reinforced soil is flexible enough to accomodate degrading channel but does not allow floodplain evolution.

Figure 5-2(b). Matrix 2: Explanations of ratings in Matrix 2.

MATRIX 3: SCREENING TREATMENTS BASED ON POTENTIAL, LONG-TERM HABITAT IMPACTS
Refer to Chapter 4 for Habitat Considerations

Suitability of Mitigation and Bank-Protection Techniques with Respect to Habitat

This Technique → **Impacts and/or Mitigates** **This Habitat Function ↓**		No Action	Other Techniques			Riparian-Buffer Management	Flow-Redirection Techniques							Structural Techniques							Biotechnical Techniques					Internal Bank-Drainage Techniques	Avulsion-Prevention Techniques		
			Spawning-Habitat Restoration	Off-Channel Spawning and Rearing Habitat	Channel Modifications		Groins	Buried Groins	Barbs	Engineered Log Jams	Drop Structures	Porous Weirs	Remove or Reduce Feature	Anchor Points	Roughness Trees	Riprap	Log Toes	Roughened Rock Toes	Log Cribwalls	Manufactured Retention Systems	Woody Plantings	Herbaceous Cover	Soil Reinforcement	Coir Logs	Bank Reshaping	Subsurface Drainage Systems	Floodplain Roughness	Floodplain Grade Control	Floodplain Flow Spreader
Suitability of Each Technique from Matrix 2:																													
Riparian Function:	Impacts To	A	A	A	D*	A	L	A	L	A	A	A	D	L	A	H	L	L	M	H	A	A	L	A	L	M	A	A	A
	Compensated By	-	-	-	D*	C	-	-	-	-	-	-	D	-	-	-	-	-	-	-	C	C	-	-	-	-	-	-	-
Cover:	Impacts To	A	A	A	A*	A	L	A	L	A	A	A	D	A	A	H	L	M	M	H	A	A	L	A	L	A	A	A	A
	Compensated By	-	-	-	C*	C	D	-	D	C	C	C	D	-	C	-	C	-	-	-	C	C	-	-	-	-	-	-	-
Spawning:	Impacts To	A	A	A	A*	A	L*	L*	L*	L*	L*	L*	D	A	A	H	M	M	H	H	A	A	A	A	A	A	A	A	A
	Compensated By	-	C	C	C*	-	D*	D*	D*	D*	D*	D*	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Complexity and Diversity:	Impacts To	A	A	A	A*	A	A	A	A	A	A	A	D	A	A	H	L	M	H	H	A	A	L	A	L	A	A	A	A
	Compensated By	-	-	C	C*	-	C	-	C	C	C	C	D	-	C	-	C	-	-	-	C	-	-	-	-	-	-	-	-
Lost Opportunity:	Impacts To	A	A	A	A*	A	H*	D*	H*	L	M	M	D	L	L	H	L*	H	H	H	A	A	A	A	A	A	A	M	M
	Compensated By	-	-	C	C*	-	-	-	-	C	-	-	D	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-
Flood Refuge:	Impacts To	A	A	A	A*	A	A	A	A	A	A	A	D	A	A	H	A	A	M	H	A	A	A	A	A	A	A	A	A
	Compensated By	-	-	C	C*	C	C	-	-	C	-	-	D	-	C	-	-	-	-	-	C	-	-	-	-	-	-	-	-
Suitability of Each Technique From Matrix 3: **S**uitable/**U**nsuitable																													

Level of Impact
* = See Figure 5-3 (b) for additional explanation.
D = Site Dependent. Depends upon site - too varied to generalize in this matrix.
The ratings for the "Impacts Caused By" are:
A = Avoids Impact. Impacts to the habitat function are generally avoided.
L = Low Impact. Potential low levels of impacts.
M = Medium Impact. Potential medium-levels of impacts.
H= High Impact. Potential high levels of impacts.
The ratings within the "compensated by" rows are:
\- = Not Applicable.
Additional options in the matrix are:
D = Site Dependent. Depends upon site conditions - too varied to generalize in the table.
C = Technique Compensates for habitat Impact.

NOTES
1. The ratings assume long-term impacts as opposed to short-term impacts. The ratings may vary if short-term impacts are under consideration. Each rating is subjective and may vary given site-specific conditions.

2. Construction may cause temporary impacts. Refer to Chapter 4 for information on how to mitigate for construction.

3. "No Action" may involve the decision to simply take no action. It may also involve solving the problem by undertaking "out-of-channel activities" (such as moving a building or structure) rather than implementing bank protection.

4. Matrix 3 is provided to assist in identifying options that will avoid or minimize impacts or will compensate for losses. Realize that this matrix is general; there will be situations that are exceptions to the matrix. The exceptions might be due to specific habitat requirements or unique site conditions. The matrices are a first effort to relate techniques and impacts; each cell should stimulate further discussion.

5. Any habitat impact listed on the matrix assumes that the habitat function is currently present. The standard of impacts to be mitigated is a regulatory issue. Possible standards include impacts to habitat currently present, or impacts to habitat that would be present in an unaltered site. Mitigating for habitat that would occur in an unaltered state is different than lost opportunity, which depends on erosion to be created.

6. The preferred bank-protection technique is the one that, in addition to solving the causes of scour, avoids the habitat impacts. Look for techniques with an "A" in the rows labeled "impacts caused by." If there are no techniques that avoid impacts, minimize impacts by looking for techniques that have low, medium and then high impacts, in that order. For every low, medium or high impact there must be provided a technique that compensates. Appropriate techniques for compensatory mitigation depends upon the mitigation target as described in Chapter 4. Compensating techniques for a particular habitat function are identified with a "C" in the rows "impacts mitigated by." Many specific techniques have a mix of C, L, M, H and A's in rows associated with "impacts caused by". In that case, consideration and weight must be given to what functions are critical or limiting, what functions cannot otherwise be mitigated and what functions might be most impacted by the projects. These conditions are also described in Chapter 4. See Chapter 5 for additional instructions on how to use this matrix.

Figure 5-3(a). Matrix 3: Screening techniques based on habitat impacts.

MATRIX 3: SCREENING TREATMENTS BASED ON LONG-TERM POTENTIAL HABITAT IMPACTS
Explanation of Matrix 3 Ratings

HABITAT FUNCTION	IMPACT CAUSED BY OR COMPENSATED BY	TECHNIQUE	RATING	EXPLANATION OF RATING
All	Impacts To, Compensated By	Channel modifications	A, C	Assumes that a full complement of habitat features is included in the channel modification project.
Riparian Function	Impacts To Compensated By	Channel modifications	D	May depend on riparian function at site (e.g., E. Wa vs W. Wa and emergent vs mature conifer forest)
Cover	Impacts To, Compensated By	Groins	F	Assumes groins are a wood-catching structure. Cover habitat depends greatly upon species and age class.
	Compensated By	Barbs	P	Barbs are too low to catch debris. Cover habitat depends upon species and age class.
Spawning	Impacts To, Compensated By	Flow-redirection techniques	L, D	Flow-redirection techniques create hydraulics suitable for spawning habitat though the habitat may vary from the habitat that is impacted.
Lost Opportunity	Impacts To	Groins, barbs	H	Assuming they are permanent rock groins rather than deformable woody groins.
		Buried groins	D	Depends upon the distance buried groins are from channel. Impact is much less if they are located at the edge of the channel-migration zone.
		Log toes	L	Log toes are considered deformable.

Figure 5-3(b). Matrix 3: Explanation of ratings in Matrix 3.

CASE STUDIES

To demonstrate the selection process, three case studies in Washington State are provided. The case-study sites vary from one another based on geography, geomorphology and level of risk. Case-study site # 1 is a rural reach of the Nooksack River, a braided river in Whatcom County. Case-study site # 2 is an urban reach of Salmon Creek in Vancouver. Case-study site #3 is an arid, rural reach of the Tucannon River in southeastern Washington.

Case Study #1: Nooksack River

Project Background

The Nooksack River Fish Habitat Enhancement and Erosion Control Pilot Project involved the remediation of severe erosion problems at two sites on the Nooksack River, using nontraditional methods. The project sites included 3,100 feet of streambank that had been progressively and severely eroding at a rapid rate for several years (*see Figures 5-4 and 5-5*). Many acres of farmland and low-lying forest had been lost, and there was concern that the erosion would facilitate floodwater access to a swale that carries water to the Everson Overflow and, ultimately, into the Fraser River watershed in Canada.

Concern about the Everson Overflow played a significant role in project initiation and funding. When the Nooksack River reaches a discharge of approximately 25,000 cubic feet per second, floodwaters overtop the Nooksack Watershed Divide and enter a tributary basin of the Fraser River. Over the past century, this overflow has led to flooding in several towns in Washington and British Columbia. By the summer of 1997, bank erosion at both project sites had cut headward into overbank swales that contribute to the Everson Overflow. Concern was raised that continued erosion would allow floodwaters to enter the swales at progressively lower water surface elevations (smaller floods). Thus, it appeared that continued bank erosion at both sites threatened to exacerbate the Everson Overflow problem.

Figure 5-4. Plan view of erosion on the Nooksack River.

Figure 5-5. Ground view of erosion on the Nooksack River.

This pilot stabilization project, designed and constructed in 1997, was carried out to test the ability of several non-riprap bank treatments to control bank erosion and associated sediment inputs, as well as to create needed fish habitat.

Site-based Assessment

The primary mechanism of failure for erosion at the two Nooksack River sites was toe erosion. There were two site-based causes for toe erosion: bend scour and a reduced vegetative bank structure associated with land clearing for agriculture. Bend scour was the dominant cause, which occurs when the erosive force shifts from the bed of the channel to the outer corner of the channel as it encounters a bend. A secondary mechanism of failure was the potential for an avulsion caused by natural aggradation in this river reach.

Reach-based Assessment

A geomorphic analysis conducted for the project indicated that channel migration was occurring in the project reach and that erosion in the project reach had extended beyond the historical limits of the meander belt. According to data from 1996 to 1997, the channel was migrating laterally, with bankline migration rates between 310 and 350 feet per year near the project sites. Lateral channel migration is a typical reach-based cause of toe erosion. In the case of the Nooksack River, meander migration was occurring at the edge of the channel-migration zone.

The Nooksack River is a wandering, gravel-bed river, typical of the western Washington region. Rivers in this region are characterized by depositional zones that form laterally unstable, braided channel segments and by transport zones that are single-thread, laterally stable reaches between the sedimentation zones. In the vicinity of the project sites, the river flows through a depositional reach that is characterized by multiple channels, extensive bar surfaces and lateral instability. Thus, the project reach of the Nooksack River is naturally aggrading and is probably in equilibrium over the long term.

Selection Process

Using Matrix 1, a number of bank-protection techniques were found to have a good level of suitability when toe erosion along a bend is the cause of erosion. Using Matrix 2, a number of bank treatments were found to have a good level of suitability when an equilibrium reach is experiencing meander migration at the edge of the channel-migration zone. When the matrices were combined, nine bank treatments were deemed acceptable. Three of the nine techniques were instream flow-redirection techniques, and the remaining six techniques were structural bank-protection techniques (several of the biotechnical techniques were also considered acceptable when used in combination with the other methods).

Several design considerations were important for determining the final bank-protection treatments used. First, the client and resource agencies would not allow the use of riprap, a structural technique that had been used unsuccessfully at these sites in the past. Second, the project budget precluded the use of expensive techniques such as log toes. And, finally, fish habitat was of primary concern. Thus, the treatment options were further screened using the first four categories of Matrix 3 (all of which pertain to fish habitat). Only four treatments were found to be acceptable at low-to-medium levels of impact on fish habitat: groins, buried groins, barbs and roughness trees.

Based on this process, bank treatments were selected that were relatively low cost, conducive to habitat formation and able to stand up to the dynamic behavior of a high-volume river (design discharge of 42,000 cubic feet per second). Because of the pilot-project nature of this work, several treatments were needed for effective comparisons to be made. With these conditions in mind, two types of treatment were selected: rock groins and log groins, with cabled, woody debris to enhance fish habitat. Bank reshaping, woody plantings and herbaceous cover were also selected for additional bank stability and habitat enhancement.

Design

Bank treatments used in this project included groins constructed of logs that were cabled to wooden piles (*see Figure 5-6, next page*); groins consisting of a rock key and foundation with an upper surface of concrete doloes (*see Figure 5-7, next page*); and groins built entirely of rock. The all-wood, log-and-pile groins were used where hydraulic analyses indicated they were durable enough for site conditions. The other site had higher-flow energy and received the dolo groins. Designs for both sites included cut-back trenches to prevent flanking of the groins, which could result in excavation of the barb keys by erosion. Both site designs also incorporated woody debris anchored to (or built into) the groins and banks. To promote bank stability, all banks were groomed back to a 2:1 slope. To protect the upper banks and to facilitate the rapid establishment of native riparian species, both designs also included detailed revegetation plans.

Figure 5-6. Log groins on the Nooksack River.

Figure 5-7. Concrete doloes with woody-material recruitment on the Nooksack River.

Mitigation

Matrix 3 identifies habitat impacts from various bank-protection techniques. Groins may cause a low impact to cover and a medium impact to riparian function, spawning and construction. To mitigate for these potential impacts, special provisions were made in order to maximize fish habitat in and around the groins. The woody and dolo groins were designed to be quite porous, thus creating "chutes" of flow as well as quiescent zones within and downstream of the groins. In addition, the porosity of the groins was designed to facilitate natural recruitment of woody debris. Furthermore, woody debris was cabled along the downstream edges of the rock and dolo groins and along the banks between groins to provide additional cover for fish. Finally, the particular arrangement of the groins would encourage development of deep scour holes near the tips of the groins, which would offer pool habitat at lower flows. The steep banks were reshaped and vegetated to mitigate for impacts to riparian function.

Monitoring

A three-year monitoring plan was developed for the two Nooksack River sites. Attributes monitored and associated monitoring techniques are shown in *Table 5-2*.

For more information on this project, contact Whatcom County Public Works Department, Division of Engineering, Whatcom County, WA, or Inter-Fluve, Inc., Bozeman, MT.

Project Attribute	Monitoring Technique
Barb and bank configuration	Yearly topographic survey and aerial photos, observations, photographs and video tape.
Erosion and deposition	Yearly topographic survey and aerial photos, observations, photographs and video tape.
Fish-habitat availability and usage	Habitat surveys, snorkel surveys.
Revegetation success	Vegetation surveys.
High-flow hydraulics	Observations, video tape of high flow events.
General site geomorphology	Yearly topographic survey and aerial photos, observations, photographs and video tape.

Table 5-2. Attributes and monitoring techniques associated with the Nooksack River site.

Case Study #2: Salmon Creek

Project Background

The Salmon Creek Bioengineered Bank-Stabilization Project was part of a multi-year effort by the Clark Public Utilities in Clark County to implement bank protection at approximately 30 sites within the Salmon Creek drainage area that had experienced recent bank erosion. The Salmon Creek watershed, located near Vancouver, is typical of basins in expanding urban areas of the Pacific Northwest that have been transformed from forest to agriculture to mostly urban land use. These watershed changes have included concurrent declines in salmon and steelhead populations, as well as increased channel erosion.

Clark Public Utilities, using money for fish-habitat restoration, identified several bank-protection project sites. The project objectives were to use innovative bank-protection technology that addresses long-term bank stability and is sensitive to fish and wildlife habitat. Early project sites (1996) typically included eroded vertical banks from three to 12 feet in height, composed mostly of fine sediments (silt) that, once eroded into the channel, threatened habitat quality within Salmon Creek. The design solution for these sites incorporated a stable rock foundation, with native-soil reinforcements, woody plantings and herbaceous cover above. Later project sites (1997) were targeted for a less-intensive bank-stabilization approach, such as the use of woody debris, coir fabrics and vegetation. At one particular site, channel modifications were used in conjunction with woody debris and woody plantings to promote bank stability and enhance habitat.

This case-study description focuses on one particular site, about 650 feet in length, where the streambank was severely eroding into adjacent properties. An expansive gravel bar was directing the channel thalweg toward a steep slope with fine sediments, and single-family residences located at the top of the slope were at risk (*see Figure 5-8*).

Figure 5-8. Eroding bank on Salmon Creek.

Site-based Assessment

The mechanism of failure at this site was toe erosion. The toe erosion had two site-based causes: bend scour and reduced vegetative structure associated with human development. The primary cause was reduced vegetative structure, a condition that occurs when woody vegetation is disturbed along the bank and riparian area, subsequently making the bank more susceptible to erosion.

Reach-based Assessment

This Salmon Creek site was located in a depositional reach with a lower gradient than upstream or downstream reaches and extensive gravel bars that occluded previous channel alignments. A bridge at the downstream end of the site, constricts the channel and causes the reach to backwater at high flows. As a result, the channel in this reach had realigned several times in the last thirty years, each occurring after a large flood event. The potential for avulsion was also a mechanism of failure as evidenced by aggradation, previous channel relocations and the presence of a downstream constriction.

Selection Process

Using Matrix 1, treatments were screened for the project site with a mechanism of failure of toe erosion due to erosion along a bend and/or reduced vegetative structure. Using Matrix 2, treatments were further screened using the reach-based considerations for an aggrading reach with a localized, downstream constriction and reduced slope. This resulted in 11 acceptable treatments, ranging from channel modifications to structural bank-protection techniques, to biotechnical treatments.

Several design considerations were important in determining the final bank-protection treatment used for this site. Since low-cost alternatives were desirable, several expensive techniques were eliminated from consideration. In addition, a combined approach was desirable in order to satisfy the client's preference for innovative treatments that benefited habitat. Most importantly, techniques were needed that would remedy the tendency for the aggrading channel to realign. Based on these considerations, channel modifications and woody plantings were selected as the most useful approach to restoring channel and bank stability.

Since fish habitat was emphasized for this project, Matrix 3 was used to identify habitat impacts of the various bank-protection techniques. The treatments used at this site generally avoid impacts to fish habitat. However, several design elements were included to ensure that habitat elements were enhanced. A backwater channel at the left channel margin adjacent to the gravel bar was excavated (lengthened, widened and deepened), and woody debris was added to provide escape and cover habitat for fish. Woody debris was also placed in the high-flow channel to enhance rearing habitat. In addition, the bank plantings were designed as a long-term benefit to fish by fostering a riparian area, which will eventually provide shade and cover for the stream channel at each site.

Design

The bank-protection techniques used at the project site included channel realignment, high-flow channel creation, and vegetative plantings (*see Figure 5-9*). The six-foot-high, vertical right bank was protected by relocating gravel bar material and realigning the channel toward the left bank. Photographic records of channel changes within the reach were used to select the most stable channel configuration. Next, material was excavated to form a high-flow channel upstream to increase conveyance and to provide some relief during flooding. It also decreased erosive potential along the newly created right-channel boundary. Finally, the slope of the eroding bank was reduced, and the roughness of the bank was promoted by planting willow clumps salvaged from the high-flow channel excavation. These treatments were combined with woody-debris placement in off-channel areas and woody plantings to promote bank stability and habitat.

Figure 5-9. Channel realignment, vegetation plantings and bank reshaping on Salmon Creek.

Monitoring

Unfortunately, monitoring was not done on this project. For follow-up information, contact Clark Public Utilities, Vancouver or Inter-Fluve, Inc., Hood River, OR.

Case Study #3: Tucannon River

Project Background

This project is located on the Tucannon River in Columbia County, on property owned by the Washington Department of Fish and Wildlife. This reach of the Tucannon River has been straightened, cleaned and diked, resulting in isolation of the riparian zone and loss of pool habitat. Most recently, the property had been managed for cattle grazing, and the left-bank riparian zone was in very poor condition. The main damage to the site occurred during February 1996, when a flow of 5,500 cubic feet per second was recorded at the USGS gauge at Starbuck, WA. The recurrence interval for this magnitude of flood is between 10 and 25 years. As shown in *Figure 5-10*, the flood scoured the left bank, formed numerous gravel bars at the site and created a braided section of channel with high width-to-depth ratios.

Figure 5-10. Left-bank erosion on the Tucannon River.

Researchers have documented a lack of spring chinook salmon spawning in the reach relative to upstream and downstream reaches. This is attributed to lack of deep pools with large woody debris cover and high water temperatures. These conditions are due to channel straightening, cleaning and diking activities following the 1964 and 1970 floods and subsequent loss of riparian-zone function.

The goal of the project was to provide a demonstration project that would address fish-habitat needs, channel stability issues and floodplain function. The habitat needs include deep pools, large-woody-debris cover, reduced summer water temperatures and over-wintering habitat for juvenile salmon. The project objective was to form a single channel with appropriate width, depth and curvature for stability.

Site-based Assessment

The primary mechanism of failure was toe erosion. There were two site-based causes for toe erosion: 1) reduced vegetative bank structure associated with grazing activities, and 2) bend scour. Reduced vegetative bank structure was the dominant cause. It occurs when the woody vegetation in the riparian area is disturbed or removed. Loss of the vegetation root structure reduces the shear-resisting strength of the bank and the ability of the bank to resist erosion.

Reach-based Assessment

This reach of the Tucannon River has been impacted by channel diking (upstream and downstream), large woody debris removal and straightening. However there were no dikes in the immediate vicinity of the site, and it is uncertain if the channel had been straightened at the site. The primary reach-based cause of erosion was large floods experienced throughout the watershed in February 1996. Many of the bridges in the Tucannon watershed were damaged or destroyed during the floods. These floods caused a rapid change in the channel form and short-term disequilibrium. The rapid change in form resulted in several braided channels at the site. The lateral erosion was within the channel-migration zone.

Selection Process

According to Matrix 1, a number of bank-protection techniques are rated as "Good" when the mechanism of failure is toe erosion caused by reduced vegetative bank structure. Using Matrix 2, a number of bank treatments are again rated "Good" when a reach is in disequilibrium caused by a large-scale flood event. When the matrices are combined, there were suitable bank-protection treatments for this particular project, ranging from channel modifications to structural bank protection to biotechnical treatments.

In Matrix 1, engineered log jams are rated G2 (meaning they are considered Good when used in combination with other techniques rated as Good) for a reduced vegetative structure bank. Since there was no immediate threat to infrastructure, the engineered log jams were accepted over other instream flow-redirection and structural bank-protection techniques, given the habitat value provided by engineered log jams.

Using Matrix 2, engineered log jams were further screened for reach conditions that are in short-term disequilibrium primarily caused by large-scale flood events, though meander migration within the migration zone could be considered as secondary. The rating for use of engineered log jams is "Site Dependent" for large-scale flood events. Jams are rated "Fair" to "Good" for addressing meander migration. Because of the low risk of impact at the site, the technique was considered acceptable.

Since this was a demonstration project, one of the design considerations included using a composite treatment, with emphasis on restoration of fish habitat. Using Matrix 1 and Matrix 2, biotechnical techniques and woody and herbaceous plantings in combination with bank reshaping were selected to increase bank stability and eventually decrease summer water temperatures.

Matrix 3 was used to identify habitat impacts of the various bank-protection techniques. Engineered log jams both avoid and compensate for all habitat impacts except construction impacts. The use of large woody debris in the jams would provide fish habitat and prevent erosion of the new bank line. The jams would collect additional woody debris and form deep pools with excellent cover. The bank between jams was not armored or diked, so the floodplain would function during floods. The jams were designed to maintain the thalweg in the new alignment, and the bankline in the "shadow" of the jams would be a deposition zone where vegetation could be re-established. The floodplain area would also be revegetated to speed the establishment of a riparian zone. Woody and herbaceous plantings are rated in Matrix 3 as "Avoiding All Impacts." Bank reshaping is rated as having a low impact on cover and riparian function and a medium impact for construction. Planting vegetation would compensate for impacts from bank reshaping and would be designed as a long-term benefit to fish by fostering a riparian area to provide shade and cover for the stream channel.

Design

Figure 5-11 and *Figure 5-12* show the project two years after construction. The engineered log jams were modeled after a technique developed by T. B. Abbe and D. R. Montgomery.[1] Key pieces were made by cabling several trees together and cabling four, three- to four-foot-diameter boulders to each piece. The boles of key pieces were buried in gravel-bar sediments up to the rootwad, against which smaller logs were racked. As a factor of safety, several four-foot-diameter boulders were placed on the rack for additional ballast.

Figure 5-11. Engineered log jams on the Tucannon River.

Figure 5-12. Engineered log jams on the Tucannon River.

Channel geometry was based on a preliminary analysis and included bankfull width (40 feet) and depth (3.5 to 4.0 feet), and meander radius (330 feet). The channel cross section shape was triangular, with a 2:1 slope on the outside of the bend and 8:1 slope on the inside of the bend. The five engineered log jams were spaced at 90-foot intervals along the meander. The stepwise progression of engineered log jams is intended to maintain the thalweg of the channel along the desired alignment. This will not prevent portions of flood flows from leaving the channel between jams, nor will it prevent the floodplain from functioning. A riprap cutoff trench extends into the bank at the upstream jam to reduce the risk of the channel cutting behind the first structure of the series.

Beyond the boundaries of the bankfull channel the soils were graded to blend into the local topography. Both banks were planted with native vegetation, including cottonwood, willow, Ponderosa pine and wild rose. Willow and cottonwood live stakes were planted in August, following the engineered-log-jam construction, but nearly all died. A second planting of live stakes, plus rooted pine and rose, was completed the following spring. These survived.

Monitoring

The preproject conditions were documented by oblique aerial photos taken in 1998. Photos were also taken from a nearby hillside in 1998 and 1999. Photographs will be taken repeatedly as significant flows bring about changes at the site. Following project completion, an as-built survey recorded the location of the new channel, thalweg, engineered-log-jam locations and widths, and the location of the edge of the 1996 eroded bankline behind the jams. The survey may be repeated if deemed necessary. There have not been any significant run-off events since the construction and consequently little change to the project.

Biologists with the Washington Department of Fish and Wildlife have conducted several snorkel surveys of the site since construction. They have verified significant use of the engineered log jams by juvenile chinook salmon and steelhead, and resident rainbow trout. There have also been several sightings of adult salmon resting at the engineered log jams. Additional surveys may occur but are not currently scheduled.

CONCEPTUAL STREAMBANK PROTECTION

The selection matrices are based on a numerical rating approach to identify possible treatment techniques that address a particular erosion problem. To aid further in the selection process, this section supplements the matrices with a qualitative description of those techniques that are consistently rated as "Good" or "Fair." For the sake of brevity, only the most common erosion problems are described here. This section also provides treatment alternatives to consider during and/or immediately following an emergency.

Before settling on any one or combination of treatments, it's important to determine whether a permanent treatment is required or if a deformable bank treatment would work better.

To stabilize an eroding bank in an area that poses a high risk to adjacent buildings or infrastructure, a permanent treatment is generally used. Such techniques typically use rocks and logs at the toe of the slope (and some distance up the slope), with the inclusion of soil or other appropriate growing media to support plants. These measures halt bank erosion at the site, while providing the physical template for the creation of aquatic habitat and establishment of riparian vegetation.

A deformable bank treatment should be considered where a small amount of continued bank erosion each year is acceptable or even preferable, but the current rate of erosion is excessive. Deformable bank treatments provide for immediate bank stabilization, using native and biodegradable materials, in order to allow healthy riparian vegetation to become established. Unlike permanent treatment materials, however, deformable bank treatments allow the bank to shift and change somewhat over time at a natural, acceptable pace. In this scenario, long-term bank erosion is minimal, and stabilization relies on maintaining good streamside vegetation.

Treatments for Scour

Scour is caused by features in the channel that disrupt the natural flow patterns and increase the turbulence in the vicinity of those features. This turbulence creates scour holes where energy is dissipated. Roughness elements placed in a scour hole are not the best solution, since their scale often eliminates the energy dissipation volume of the scour hole. Rather, adequate volume in the scour hole should be provided to assist in energy dissipation.

Before settling on any one or combination of treatments, it's important to determine whether a permanent treatment is required or if a deformable bank treatment would work better.

An effective scour hole does not transfer any carry-over energy downstream. It therefore offers some protection to downstream banks and channel. The importance of scour holes cannot be downplayed; destroying them by straightening the bankline can lead to more complex and destructive dynamics downstream. If the scour hole is just beginning to evolve, you can expect lateral and bed scour until the hole has matured and stabilized.

Balancing the need to preserve a scour hole while preventing further erosion requires the use of anchor points. Anchor points are either natural (e.g., tree, rock outcropping) or artificial hard structures (e.g., rock trench) at the upstream and downstream end of an energy sink. They fix the upstream and downstream points of the scour hole so volume cannot be gained by erosion in the upstream or downstream directions. By fixing these points, volume is gained by forcing erosion either laterally, or (even better) vertically, by eroding the channel bed and creating a deep pool.

Treatments for Toe Erosion

Toe erosion is the most common mechanism of failure in Washington State. Toe erosion results as material is entrained from the toe and/or surface of the bank by flowing water. Toe erosion may be caused by reach- and site-based causes. Common site-based causes include reduced vegetative bank structure, smoothed channel and bend scour. Common reach-based causes include meander migration, aggradation and degradation.

Treatments to consider for toe erosion caused by reduced vegetative bank structure include restoring a hospitable environment for vegetation by applying toe protection and reshaping and planting the bank. Toe protection can either be permanent or deformable depending upon the level of risk and the location of the streambank in the migration corridor. Fencing out livestock and establishing a riparian buffer are very effective solutions. Techniques to redirect erosive flows away from the bank and to provide roughness can be used in combination with the above techniques. Groins should not be used since they create strong eddies along the bankline.

Toe erosion along a bend (bend scour) can result from either natural or human activities. A channel that is in equilibrium and migrating will create bend scour. Likewise, a channel that is in disequilibrium will also create bend scour. It is important to recognize whether bend scour is occurring in an equilibrium or disequilibrium channel. Applying structural bank treatments to bend scour in an equilibrium channel can have profound impacts on upstream and downstream channel dynamics as discussed in Chapter 3, *Reach Assessment*. These techniques disrupt the natural meander migration and patterns of erosion, often resulting in the need for even more bank protection. Deformable treatments are the most appropriate since they allow for gradual meander migration. These are discussed in more detail in the following section. Applying structural bank treatments in a disequilibrium channel experiencing bend scour can also have profound impacts upstream and downstream. For these reasons, deformable techniques should also be considered first. If the level of risk to infrastructure is such that any further erosion is not tolerable, then flow redirection and structural techniques may be necessary.

Toe erosion is also caused in a channel that has been smoothed. The best solution is to add what was originally lost; that is, *add roughness elements*. Roughness elements, such as woody debris, woody vegetation and randomly placed boulders can be incorporated into the stabilized bank to enhance the hydraulics and habitat of the reach. Other appropriate techniques include grade control, such as a drop structure or porous weir.

Treatments for an Aggrading Channel

A reach aggrades when more sediment is transported into the reach than can be transported out of the reach. Aggradation occurs either naturally or is induced or accelerated by human activities. The reach-based causes for aggradation are reduced hydrology, increased sediment supply, downstream constriction, reduced slope, or channel confinement. Refer to Chapter 3 for more information on the reach-based causes of aggradation.

If aggradation is caused by an increased sediment supply, reducing the excess supply of sediment from upstream sources is the most effective solution. Sediment transport to the riverine system originates from different hill-slope and valley morphologies and is dominated by either fluvial or mass wasting processes.[2] Other sources originate from the channel itself due to excessive bank erosion. One way of reducing the excess sediment supply is to increase the capacity for sediment transport within a reach by modifying the channel to an appropriate pattern, profile and cross section. The feasibility and design of this concept requires a detailed analysis of sediment transport characteristics and hydrology. Identifying and selecting a migration corridor that extends beyond the current active channel should also be considered. Broadening the channel's migration corridor will allow aggradation and recovery to occur naturally.

Debris jams play an important role in bedload transport by providing storage of bedload and metering the rate of downstream transport. Many river channels have experienced a decline in woody-debris input. Constructing a debris jam upstream from an aggrading reach may reduce the rate of bedload supply transported downstream. Alternatively, constructing a midchannel debris jam in an aggrading reach will create a stable island immediately downstream. This has a stabilizing effect on the total channel cross section. However, if the cause of aggradation is a confined channel or a downstream constriction, then engineered log jams are not recommended, since they can further confine or constrict the channel.

Removing or reducing a constriction that is causing aggradation is another way of treating an aggrading channel. If the constriction is a bridge, consider removing or redesigning the bridge. A bridge can be redesigned to reduce the constriction by increasing the channel area under the bridge (e.g., increase span and/or vertical clearance) or streamlining the bridge approach (e.g., use channel modifications and/or wing walls). The decision to remove or redesign a structure, such as a bridge, can be costly, and it must be balanced with economics and the level of risk to property that is threatened by erosion. If the constriction is a culvert, consider removing or redesigning the culvert. If the constriction is due to a debris pile, consider partially dismantling the debris pile. However, debris that is removed must be placed back in the channel as habitat-restoration elements, used in other bank-protection projects, or stockpiled for future habitat-restoration efforts. The decision to remove a debris pile must be carefully considered with respect to habitat functions that may be impacted.

If the floodway has been confined by a levee or road, *setting back the confinement or removing it* will allow the channel to regain its natural channel length and slope. The minimum outer limit of the setback should be at the edge of the channel's natural meander belt. Optimally, the setback should be far enough beyond the channel's meander belt to provide floodplain function and an appropriate level of flood management to adjacent properties.

Removal of sand and gravel to alleviate aggradation problems should only be considered after analyzing and exhausting more preferable techniques. This technique requires a detailed analysis and understanding of the channel hydraulics, hydrology, sediment budget and biological effects of removing materials. Locating appropriate sites for removal is crucial. The most common site for gravel removal is where the channel is aggrading. However, this is most often a short-term solution; it may have significant impacts on habitat, and it requires ongoing maintenance. Other sites to consider for removal are upstream from the aggrading reach where the material is stored, including the initial upstream source of sediment, such as an upland mass slide. Optimally, the location for removal should be identified as part of local watershed planning studies.

Treatments for a Degrading Channel

A common cause of degradation is an increase in hydrology. The optimum long-term solution is to identify and *remedy the cause of the increase in hydrology* rather than focusing only on the eroding bank. In other words, don't just treat the symptom; treat the cause. Under the best of circumstances, this would involve local-government planning efforts in the development of basin or watershed studies and the implementation of a *storm-water management ordinance*. The next-best solution is to redefine the channel to accommodate the anticipated long-term inputs of sediment and flows, consisting of a modification of the channel's pattern, profile and dimensions to fit the new hydrologic regime. Examples include lengthening, roughening, widening and/or sloping the banks of the channel. However, if only a short-term solution is available, appropriate techniques include grade stabilization and use of bank protection to increase roughness along the channel bank.

The primary concern to be aware of if applying bank-protection treatments in a degrading channel is the potential for the river to undermine the treatment by lowering its channel bed. Consequently, the design of a bank-protection technique applied at the toe of a bank must be sufficient to withstand down-cutting. This resistance is critical to project performance (in addition to depth of scour calculations based on existing conditions).

To minimize or prevent further channel lowering, consider stabilizing the bed using *grade-control structures,* such as porous weirs or drop structures. Construction of grade-control structures will prevent degradation upstream from the structure. Degradation downstream from the structures will continue if the cause of degradation is not controlled. *Bank and/or bed stabilization* placed on a channel that is actively incising has a strong potential for failure due to undercutting of those treatments; consequently, an actively incising channel requires aggressive bed stabilization.

Raising the channel to reconnect the old floodplain surface is another option. This technique requires selecting appropriate locations to tie into the old channel, but it may prove difficult if tie-in points are similarly incised.

Where a channel is shortened, *lengthening the channel* and adding roughness elements are possibilities. This will require a comprehensive study of undisturbed reaches or reaches in a geomorphically similar river to understand the river's natural channel pattern, profile and dimensions. Based on this information, the straightened reach can be rechannelized to mimic its natural pattern, profile and dimensions. Roughness elements, such as woody debris, woody vegetation and randomly placed boulders, can be incorporated in the rechannelized reach to enhance the hydraulics and habitat of the reach.

Relocating the channel to reconnect the old floodplain surface around an incised reach can be highly effective. However, for this treatment, the abandoned channel must still be treated so as not to recapture the main flow at a lower elevation.

Another alternative for treating a degrading channel is to *enhance the natural, incised-channel evolution process* by widening the incised channel. This will facilitate the formation of a new, inset floodplain surface at a lower elevation than the pre-incision surface.

Treatments to Prevent Avulsion or Chute Cutoff

Where a potential for channel avulsion or chute cutoff due to aggradation is recognized, it is important to determine the cause for that aggradation. Techniques that prevent avulsion or chute cutoff will require long-term maintenance if the causes of aggradation are not addressed.

Where overland flow is concentrated and creating a potential for avulsion or chute cutoff, *floodplain roughness and flow spreaders* can help reduce this potential. *Trees and/or large woody debris* can be placed in a series of rows perpendicular to the direction of overland flow to form small dams that are porous and collect debris. They dissipate flow energy and distribute the flow across the floodplain.

Another means of controlling overland flow is to *construct a floodplain flow channel* to convey overland flows back to the river. A floodplain berm may be used in conjunction to direct flows to the floodplain channel, especially if the cause of overland flow is the presence of floodplain mining pits. The channel must be armored to prevent scour, and egress must be provided to prevent fish stranding. An abandoned channel may be used as a floodplain flow channel.

Grade control involves creation of a thick pad of heavy rock or large woody debris placed below grade in the floodplain. The purpose for grade control is to prevent surface erosion or nickpoint migration caused by overland flow. Soil can be placed on top of the grade control and planted with vegetation. Grade-control measures can be used in conjunction with a floodplain flow channel. They do not prevent overland flow during flood events. This treatment does not eliminate a flood hazard, though erosion will be minimized or even prevented.

The least-appropriate technique for dealing with an avulsion is constructing a levee. Ironically, this has been the historic technique of choice. Because the cause of an avulsion is floodplain surface erosion and not direct bank erosion, a revetment is not the most appropriate technical or economical solution. The only situation in which a setback levee is recommended is if there is a high level of risk to property or life and all other techniques have been thoroughly investigated and eliminated.

The least-appropriate technique for dealing with an avulsion is constructing a levee. Ironically, this has been the historic technique of choice.

Flow spreaders are also used in combination with other other bank-protection techniques where there is a potential for a chute cutoff. Chute cutoffs differ from an avulsion in that a chute cutoff is a type of meander cutoff that changes channel alignment on a smaller scale than an avulsion. Chute cutoffs occur when a bend in the stream becomes so tight that it causes sediment and debris to deposit and creates backwatered flow conditions in the upstream limb of the bend. The backwatered conditions increase the frequency of over-bank flows. As the flow shortcuts across the bar and re-enters the channel on the downstream limb of the bend, erosion and the development of a new channel or "chute" results. For these reasons, it is critical to consider both streambank-protection techniques that address meander migration and floodplain erosion-control techniques, such as floodplain roughness and flow spreaders.

If a channel is fully avulsed or a chute cutoff has occurred and the new channel is in an acceptable location, it may be appropriate to enhance the new channel rather than return the channel to its original course. Treating a newly avulsed channel is similar to treating an incised channel. Defining an appropriate channel width and shape promotes geomorphic equilibrium on the new channel segment. Erosion control is necessary if downstream sediment loading is excessive. Where livestock use is high, avulsed channel segments should be provided with a protected riparian buffer zone to allow natural recovery of the new segment, including obtaining easements, planting and fencing the buffer.

Treatments for Emergency Conditions

As described in Chapter 4, emergency treatments may be implemented during a flood event, or when conditions remain unstable. Where floodwaters are high and access to the channel is limited due to physical and safety constraints, treatments involving dumping or placement of rock along the bank from the top of the bank may be considered. Since visibility of the bank and toe area are usually limited by high water, the orientation of installed rock materials is difficult to evaluate until floodwaters have receded. Another treatment involves placing rock at the top of the bank, so that, as the channel migrates, the rock is launched, eventually preventing further bank retreat. Other treatments include exposed and buried groins, anchor points and avulsion-prevention techniques in the floodplain, such as placement of large woody material or roughness. An emergency treatment will likely require further construction after the recession of flood waters to ensure it is has an adequate key and to incorporate habitat measures as mitigation. An emergency treatment may also need to be replaced by a more appropriate treatment measure that addresses the site and reach conditions, as well as risk, habitat and design considerations.

An emergency treatment may need to be replaced by a more appropriate treatment measure that addresses the mechanism and causes of bank erosion.

DESIGN CONSIDERATIONS

Streambank-protection designs must consider many components and variables. Often, these are aspects of design that need to be incorporated into a solution; others are fundamental considerations that guide selection of a particular treatment. All of these require consideration within the context of mitigation needs (see Chapter 4). The design process requires an iterative approach of "solving" for these various components; that is, providing a solution for one aspect and then adjusting it as another aspect is considered.

The design process requires an iterative approach of "solving" for various components; that is, providing a solution for one aspect and then adjusting it as another aspect is considered.

The following subsections address important components of the design process for each of the functional protection techniques described previously. The design processes have been organized in a chronological sequence as a designer would address them. For example, the erosive energies at a site (shear and scour) are considered first, while the effects on channel geometry and the type of revegetation are secondary. However, the importance of these design considerations varies both from site to site and according to the type of technique employed. For some locations or technique groups, a component may be less important (or not important at all), while in others it may be the most significant aspect of the project.

Bank Resistance to Shear Stress

In Chapter 2, the effects of shear were examined to identify the mechanisms of bank failure. It is also imperative to calculate a value of shear stress to determine an appropriate bank-treatment design.

Recognize that, once a bank is stabilized, it is altered from pre-existing conditions; the shear stress at the site after construction may be different from preconstruction conditions. Thus, if a channel cross section is changed substantially, one must use proposed conditions to calculate a new shear stress.

Recognize that, once a bank is stabilized, it is altered from pre-existing conditions; the shear stress at the site after construction may be different from preconstruction conditions.

Shear stress is calculated by:

- measuring the dimensions of a channel cross section (see Appendix F, *Fluvial Geomorphology*),
- determining the water depth at the river stage at the proposed design discharge (see Appendix D, *Hydrology*),
- determining the slope of the water at this same river stage, and
- using these parameters to calculate shear (see Appendix E, *Hydraulics* for appropriate equations).

Shear stress is vertically distributed within a channel cross section (see Chapter 2); therefore, the bank treatment can be designed to account for these vertical differences. Where bank shear is greater near the toe of slope, rock or woody material might be used to provide stability. Midslope bank stabilization might consist of biodegradable, erosion-control fabrics that will provide protection until vegetation is established. The top of the slope might require minimal stabilization (e.g., simple seeding and mulching).

Shear is also greater on the outside of bends, up to 2.5 times greater than the inside of a bend (see Chapter 2). Thus, bank-treatment design needs to account for the lateral position within a bendway. The amount of shear that a site might be exposed to thus depends upon the channel slope, the depth of the water at a particular design flow, the location up the bank and the position in the channel (in a straight reach or bend).

Toe Protection to Resist Scour

In order to protect against continued scour, it's important to identify the type of scour so that maximum scour depth can be calculated for the bank-treatment design (Chapter 2). Anticipating maximum depth of scour helps identify the type and depth of toe foundation needed to provide a firm base for a stabilized bank.

Determining the maximum depth of scour is accomplished by:

- identifying the type(s) of scour to be concerned with at a site;
- calculating the depth for each type of scour;
- accounting for the cumulative effects of each type of scour occurring at the site (if more than one is present); and
- reviewing the calculated scour depth for suitability based on experience from similar streams, conditions noted during the field visit and an understanding of the calculations.

Equations are available to calculate the maximum depth of each type of scour (Appendix E). These equations are type-specific (e.g., a bend scour equation will give you an erroneous value if the cause of erosion is actually constriction scour). The equations are also empirical; they are based on repetitious experiments or measurements in the field and, therefore, can be biased towards a specific type of stream where the data was collected. For example, some equations are based specifically on sand-bed streams or, in the west, granular beds, while other equations are based on eastern streambeds with cohesive soils.

In addition to calculating the scour forces on the bed, it is also important to know the composition of the existing bed materials when designing a bank-protection project. It is likely that the existing materials are insufficient to resist scour and must be augmented or reinforced with additional materials. Where existing bed materials are substantially smaller than placed materials, some form of protection against entrainment or piping must be used. A gravel filter layer or a synthetic construction fabric is typically used in such situations as a barrier between native and placed materials.

Appropriate Channel Geometry and Roughness

Considerations of channel geometry and roughness should include:

- evaluating the effects of encroachment,
- maintaining sediment continuity, and
- providing an appropriate planform.

These aspects are described in Chapter 3 and highlighted in this section.

Encroachment involves placing materials or configuring a stabilized bank to extend into the channel or narrow the channel. In some situations, bank-stabilization measures do not encroach on a river and, thus, have no impact on channel geometry and associated flow conveyance. For example, in a river with a width of over 100 feet, placing a bank treatment that extends into the channel a few feet will generally have no effect on conveyance or flow characteristics. However, in smaller channels where *any* encroachment will have an effect, or in larger channels where encroachment may be substantial (for example, with groins or barbs), the effect of encroachment should be evaluated in design.

The effects of encroachment include:

- creating localized flow turbulence (which may be desirable for habitat creation, or undesirable because of increased shear or scour forces);
- shifting the deepest part of the channel cross section (thalweg), which may affect downstream erosion and deposition patterns;
- reducing conveyance, thereby increasing the frequency of overbank flows (flooding); and
- adversely affecting aquatic habitat that exists along the channel margin.

Roughness can have a substantial effect on the amount of encroachment. Grasses generally do not encroach on a channel conveyance, whereas a stand of dense trees along the banks and floodplain restricts conveyance. Channel roughness is important to channel function and health. Roughness dissipates energy away from the soil surface, thereby reducing surface erosion (for example, willow branches absorb energy that would otherwise be expended on a streambank). Roughness promotes the deposition and storage of sediment. From a habitat perspective, roughness can be very important, as it usually provides habitat for fish in the form of cover and refuge.

Channel roughness is important to channel function and health.

Maintaining sediment continuity through a project reach is also an important consideration of channel geometry and roughness. As a bank-stabilization project is designed, the width, depth, slope and roughness of the channel should be maintained or improved to provide for the desired sediment-transport regime. For further discussion of sediment continuity, see Chapter 3.

Lastly, the shape of the stabilized bank in planview should be considered to ensure that the orientation of the bank relative to a bend is appropriate (i.e., not too tight). Again, refer to Chapter 3 for a discussion of this consideration.

Gradual Bank Deformability

As discussed earlier in this chapter and also in Chapters 3 and 4, bank-protection measures can be designed to be permanent (fixed in place) or to gradually change over time. During the design process, the question should be posed whether or not bank protection needs to remain in place permanently, for example, to protect a building or a bridge or some other infrastructure with a long life expectancy. Conversely, if the erosion problem is in a setting where the rate of erosion needs to be greatly reduced, but not altogether stopped, then a deformable bank might be designed. Deformable banks can be used where there is a riparian corridor, agricultural land use and where minor erosion will not threaten infrastructure.

Deformable bank-protection measures do not impinge on natural, long-term, meander-migration processes (described in Chapter 3); and, thus, do not exacerbate upstream and down-bank instability as do permanent stabilization measures. Deformable protection measures have the added advantage of having less impact on channel stability and aquatic and terrestrial habitat, providing for long-term planform deformability without adversely impacting the migration patterns of streams and rivers.

Deformable bank protection includes a biotechnical bank-protection treatment for the portion of bank above the water surface. In some situations, this level of protection is sufficient. Where below-water protection is required against shear forces (where the native bed and bank materials are readily eroded), deformable bank toes might include those made from small wood and gravel, or from gravel wrapped in biodegradable erosion control fabric as shown in *Figure 5-13*.[3] In these applications, the gravel or cobble approximates the size of the largest gravel or cobble in the stream. Once the wood or fabric decays, the gravel or cobble can be gradually eroded. By that time, the above-water portion of the bank will be vegetated, resisting erosion.

Deformable bank-protection measures do not impinge on natural, long-term, meander-migration processes and, thus, do not exacerbate upstream and down-bank instability as do permanent stabilization measures.

Figure 5-13. Gravel wrapped in biodegradable fabric serves as a deformable bank.

Soils and Subsurface Materials

Another design consideration is bank material, which may be cohesive (with a high silt/clay content) or noncohesive (largely sands and gravels), have a large percentage of rock or no rock, be stratified (layers of differing materials), nonhomogeneous (differing from one point on the bank from another nearby) or consistently the same. Topsoils can be thick, thin or nonexistent.

Although bank treatments may be placed over these materials, it is still important to identify their composition for revegetation design and technique selection. Subsurface materials may need to be separated from placed materials (to prevent piping or particle-by-particle transport of fines through the soils by flowing groundwater). Subsurface materials and topsoils may also be used in constructing a stabilization technique (for example, by using large rock found in the bank or using topsoil as a growing medium for fascine installation).

Limits of Vegetation Establishment

Design of bank-stabilization measures that involve native-planting restoration will need to account for the lower limit of vegetation in a channel. Within each stream segment, the lower bank limit where herbaceous species (grasses and forbes) and woody species (shrubs and trees) survive is largely dictated by hydrologic conditions. (see Appendix H, *Planting Considerations and Erosion-Control Fabrics*). Plant species are adapted to tolerate varying levels of inundation for different periods of time (i.e., the duration and frequency of flows). The lower limit of vegetation is exhibited in stable stream reaches by the lowest elevation where older or mature plants are found.

Bank-stabilization measures using plants that rely on vegetation for long-term stability must account for this lower vegetated limit. In the long-term, plants cannot be expected to survive below this elevation. Thus, this elevation often dictates the height of hardened toe features (rock or logs), with the recognition that the placed materials, not plants, will have to provide stability below this point. It is important to consider the rooting depth and type of plants when determining the lower vegetated limit. Grasses, for example, have a relatively shallow rooting depth and may not provide much stabilization below the lower vegetated limit. Larger trees, however, have extensive root systems, providing stabilization a significant depth below the limit.

It is important to consider the rooting depth and type of plants when determining the lower vegetated limit.

The lower vegetated limit is generally not determined by a flow of a given hydrologic probability (see Appendix D). It is best determined by measuring the base level of existing, mature vegetation within a noneroding portion of channel. Where no examples exist near a project site, collect the information further upstream or downstream and extrapolate to the project site using stage-discharge relationships for the channel cross sections in question.

Plant Ecology and Riparian Habitat

Successful bank-protection projects depend upon an understanding of the plants available for use. In selecting appropriate plants, consider the objective of revegetation. Plants may be used to:

- provide surface-erosion protection (where grasses may be preferable),
- buttress unstable slopes (where extensive or deep-rooting trees may be desirable),
- create shade to moderate the stream-water temperature (where fast-growing trees or those with leafy canopies might be appropriate), and/or
- reduce surface-water velocities across a floodplain by distributing flow (by increasing surface roughness and by collecting woody debris) or by preventing particle entrainment (by providing root and shoot protection).

In addition to choosing appropriate species for appropriate locations, other considerations include:

- physical status of plants to be used (e.g., whole transplant, seed, cutting, bare-root stock, containerized, or ball and burlap);
- time limitations for planting (e.g., dormant cuttings);
- initial maintenance required (e.g., irrigation, weed control, or beaver and other animal control);
- succession of plants over time (assuming contributions of plant materials from upstream); and
- time scale within which vegetation must be structurally effective.

It is also important to consider the effects of these plants on channel conveyance. As shrubs and trees mature, they have the potential of encroaching into the channel cross section and increasing the frictional roughness of the channel margins. Roughness can be estimated for intermittent and full grow-out conditions (when shrubs may be excessively brushy or when trees mature). Roughness can be used in hydraulic calculations to estimate changes in shear stress or channel conveyance (see Appendix E).

Aquatic and Fish Habitat

Aquatic- and fish-habitat considerations should include existing site and reach habitat, and potential site and reach habitat. First, alterations or impacts to existing habitat should be avoided, minimized or mitigated as part of selection and design (see Chapter 4). When selecting and designing a project, recognize that an eroding channel is not static; in the process of erosion, habitats are formed. Likewise, any mitigation should be designed to evolve as the channel evolves. The most elegant bank-protection solution mitigates by avoiding habitat impacts and, in fact, restores habitat.

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Second, biological capacity and habitat potential should be incorporated into a bank-protection project and should not affect the full habitat potential of the site and reach. An understanding of the biological needs and the effects of a bank-protection project are essential in order to assess the habitat impacts and habitat potential of a site and reach. A detailed discussion of these needs for various species of fish and wildlife and at various life stages is provided in Appendix G, *Biological Considerations*. An annotated bibliography, prepared by the Army Corps of Engineers, is included in Appendix K, *Literature Review of Revetments*; it describes biological effects due to stream channelization and bank stabilization.

Composite Treatments

Bank-protection techniques might consist of a single type of treatment from the toe to the top of the streambank. More commonly, a treatment varies from toe to top, depending upon the amount of scour and the vertical distribution of shear up a bank. In these settings, a combination of treatments might be employed. Rock or logs may be used as a roughened toe, and vegetative techniques might be used up a bank slope.

More commonly, a treatment varies from toe to top, depending upon the amount of scour and the vertical distribution of shear up a bank.

The use of composite treatments includes conditions where internal drainage influences bank stability. In settings where rapid draw-down occurs (see Chapter 2), especially in a flashy stream with streambank soils composed of silts and clays or in inter-tidal zones, designs should provide for internal drainage. Drainage reduces the potential for mass failure and toe erosion (caused by differential hydrostatic pressures) by using a buried chimney drain, a layer of rock within the bank, or a synthetic sheet drain.

Bank treatments also include internal slope reinforcement in conditions where mass failure is a mechanism of failure. Surface-level bank-protection techniques have little influence on failures caused by more deep-seated geotechnical instability. In some settings, techniques can be incorporated to improve internal stability. For example, incorporating layers of geogrid within a reconstructed bank provides internal stability.

Upstream and Downstream Transitions

Bank-protection design focuses on the section of eroding bank. It is also necessary to design transitions from the bank treatment (along the eroding bank) into the existing stable bank (that is, upstream and downstream from the eroding bank). Successful transitions prevent erosion from extending beyond a treated site. Transitions are important, since failure of the transition might threaten the entire treatment. Transitions include tying bank protection into existing stable features (such as mature trees or a bridge abutment). Where stable endpoints do not clearly exist, transitions might involve modifying the treatment to create an abrupt, diagonal angle into the bank, preventing the flow from "end-running" around the bank protection.

Designing Around Existing Bank Protection

Bank protection is commonly installed in proximity to already existing bank protection. Designing bank stabilization near existing bank protection requires combining habitat and geomorphic effects of the existing and proposed bank treatments. Refer to Chapter 3 for a discussion of the possible response of channel meanders to bank stabilization and Appendix F. Where the existing bank protection is not adequate, remove and/or replace the existing protection. Removal and/or replacement allows more flexibility to protect or create aquatic habitat.

Floodplain Considerations

It's important to identify the location(s) where avulsion can occur by inspecting the floodplain and overbank areas and by determining those locations where topography is lower or vegetation is reduced (or both). For an accurate assessment of a large-scale problem, undertake a topographic survey of a site, in conjunction with field mapping of vegetation, zones of erosion, high-water marks and photos. This information can be used for determining floodwater patterns and erosive energies on the floodplain at various flows (see Chapter 2).

Hydraulic modeling can be used with measured topography to identify water surface elevations associated with various floods. Most low-effort, hydraulic models (such as the U.S Army Corps of Engineers River Analysis System-HEC-RAS[4]) do not deal with depicting split flows across a floodplain (for example, over an uneven floodplain surface or at the initial stages of floodplain overtopping). Nonetheless, with careful attention to stage/discharge relationships, one can predict which areas of the floodplain will be more susceptible to erosion than others.

Using floodplain topography and hydraulic models, the average anticipated shear stress on the floodplain surface is calculated (Chapter 2). The amount of shear that a floodplain site is exposed to will depend upon the depth of the water at a particular design flow. It is important to calculate an average value of shear stress first, then, to determine an appropriate treatment design for the floodplain surface. However, the actual site-specific shear stress may be dictated by topographic or vegetative variability as flows recede. Flows tend to concentrate in one or more locations across the floodplain as floodwaters recede, forming single channels of overbank flow across the floodplain. Where overbank flow returns back into the main channel, headcuts may form. These headcuts can migrate upstream across a floodplain and are the primary cause of an avulsion (see Chapter 3 and Appendix F).

Material Placement in the Floodplain

Placement of nongrowing medium on the floodplain surface, such as small- to medium-sized woody material, helps to distribute flows and increases surface roughness (thereby reducing the potential for avulsion). Placement of such materials requires attention to size, location, distribution and measures for securing (if necessary). Water levels (from stage/discharge relationships) and erosive energies (from hydraulic models) are used to guide selection and placement of materials. Some design considerations include buoyancy, accumulation of material in undesirable locations and making use of a combination of materials (such as plants and small, woody materials).

Other Mechanisms of Failure

While not covered in detail in these guidelines, other site-specific mechanisms of failure might need to be considered to successfully select and design a bank-protection project. Additional failure mechanisms include: wave action on large rivers caused by wind or boat traffic, large-scale woody debris movement or collection in jams, the effects of ice (sheet ice, anchor ice and ice jamming), earthquakes and the impacts from how the land is used (such as with high recreational traffic or where vandalism might be prevalent). More information will be provided about these failure mechanisms as these guidelines are updated.

Physical Site Limitations and Project Constructability

During the design process, one must consider how a particular bank-protection technique would need to be installed. Site limitations dictate whether (or at least how) a technique is built, including site access, dewatering, and sediment and erosion control. How to best access a site during construction depends on the type of heavy equipment needed (if any) and the limitations imposed by this equipment. For example, a rubber-tired backhoe may not be able to drive up a steep slope; a small excavator may have limited reach, or a standard dump truck may have inadequate clearance or traction in a wet, unstable streamside setting. See Appendix M, *Construction Considerations* for more information about project construction.

Also note the type and amount of materials required and how to best transport materials to the site. Dumping rock from the top of the bank damages riparian vegetation, and large quantities may require a staging area. Access directly up the channel may have the least impact (or most impact) of all methods. Construction can cause undesirable impacts to a site but can be minimized with careful and creative approaches to site access (see Chapter 4 regarding mitigation for construction impacts).

One must consider during the design phase whether and how a site will need to be dewatered. Water may be entirely diverted around a project (with pump and pipe, a coffer dam, or a diversion tube). In other locations, the site may be isolated from flowing water so that work can occur in standing water (using barriers, sediment fences, or coffer dams). For emergency projects, work may occur directly in flowing water during a receding limb of a flood, when turbidity is already high. Diverting flow and dewatering a site is difficult if not adequately planned; and, if poorly implemented, it can prevent a project from being constructed.

Consider during the design phase how to control erosion and minimize sediment inputs to the stream. Erosion control typically involves containing surface flow with berms, silt fencing or other measures. With streambank-protection projects, erosion-control measures may be placed a number of times sequentially in order to contain a site during different project phases. For example, a silt fence might be placed at the toe of a slope as access is created, then moved upslope as a log toe is installed. The silt fence may be removed altogether once a project is completed and the site is protected with erosion-control fabric.

CONCLUSION

There are a tremendous number of considerations to take into account before designing and installing streambank-protection treatments. Assessing site and reach conditions, defining project objectives and design criteria, and identifying risk, mitigation and design considerations are integrated to determine the best possible bank-protection treatments. Either taking no action or selecting the treatment or combination of treatments that meets all of these needs is the most desirable direction to pursue. The concepts and techniques discussed thus far in these guidelines are illustrated in Chapter 6.

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CREDITS

Figure 5-4. Source: Inter-Fluve, Inc.
Figure 5-5. Source: Inter-Fluve, Inc.
Figure 5-7. Source: Inter-Fluve, Inc.
Figure 5-8. Source: Inter-Fluve, Inc.
Figure 5-13. Source: Inter-Fluve, Inc.